A FUZZY NUMBER BASED METHODOLOGY FOR HARMONIC LOAD-FLOW CALCULATION, CONSIDERING UNCERTAINTIES

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Abstract — Nonlinear devices are being increasingly used in power systems and, as a consequence, harmonic distortion is a continuously growing phenomenon. Since linear and nonlinear loads are usually uncertain variables that, in addition, vary constantly, probabilistic methods for harmonic load-flow calculation have been developed to quantify the resulting random harmonic voltages. More recently, a possibilistic harmonic load-flow based on fuzzy sets theory has been proposed with the same objective. Although the possibilistic approach seems better suited to deal with the kind of uncertainty usually found in practice, the Classic Fuzzy Solution on which this methodology relies exhibits some drawbacks. This paper proposes a possibilistic harmonic load-flow based on the Marginal Joint Solution, which overcomes two major limitations of the Classic Fuzzy Solution approach: the lack of fuzzy linear loads models, and the over-and underestimation of the harmonic voltages.

Keywords — Harmonic load-flow, fuzzy sets theory, nonlinear programming.

1. INTRODUCTION

Power system harmonic load-flow methods have been developed in order to predict and solve problems like harmonic resonance involving capacitors or cable capacitances, harmonic filters design, acceptance for connecting large nonlinear loads, etc.

Harmonics in electric power systems do not have deterministic behavior because nonlinear devices are turned on and off and change their operating mode in an unpredictable way. Moreover, some parameters of linear loads like their active and reactive power and especially their composition (percentage of electrical motors, reactive power compensation, etc.) are usually known with uncertainty too.

In this context, it is often useful to calculate some measure of the likelihood of the harmonic voltage levels, and how they vary for different scenarios. Models based on probabilistic theory are being applied for this purpose (Esposito et al., 2001a, b; Baghzouz et al., 2002). In principle, probabilistic models are able to provide a very comprehensive and useful picture of the random harmonic behavior; however, in order to exploit this capability, stochastic input variables have to be known and properly described in probabilistic terms.

In practice this is seldom possible due to the lack of statistical information, and because some parameters are not really random in nature but rather imprecisely known.

In the last few years, possibility theory arises as a powerful tool to deal with this kind of uncertainties. Like models based on probability, those based on possibility rely on measures that quantify uncertainties or likelihood, and allow calculating how these propagate from the inputs or the parameters of a system into its outputs. Possibility theory can be suitably formulated in terms of fuzzy numbers, hence taking advantage of many of the developments in this area.

In particular, possibilistic models are usually simpler and computationally more efficient than their probabilistic counterparts, but the key feature certainly is their ability of modeling expert knowledge, opinions, incomplete information and other kinds of evidence, very common in the area of harmonic studies, that cannot be properly handled by probabilistic models. It should also be noted that when this kind of knowledge is expressed in probabilistic terms by resorting to somewhat arbitrary criteria, meaningful accuracy of the more demanding probabilistic models may become deceptive.

At present, possibility and fuzzy number theories are being used and investigated in areas closely related to harmonic load-flow, such as signal assessment, classification of perturbations, fuzzy power frequency load-flow, etc. (Chan et al., 1993; Miranda et al., 1991; Dimitrovski and Tomsovic, 2004). However, only a few bibliographical references exist about fuzzy harmonic load-flow (Hong et al., 2000), which is an incipient research subject. An analysis of the reported harmonic load-flow methodology based on fuzzy numbers reveals the following unresolved issues:

- The methodology relies on the so-called Classic Fuzzy Solution (to be described later), which could overestimate or underestimate the harmonic voltages.
- Even though linear loads could have a major influence in the harmonic load-flow (Burch et al., 2003), uncertainties in their power and composition are not modeled and cannot be handled in the formulation.
- It seems that only a simple possibilistic model can be implemented for nonlinear loads, namely the fuzzy real and imaginary harmonic current components themselves that nonlinear devices inject into the network.